National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades K–12

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Educational Brief

CASSINI SCIENCE INVESTIGATION

What Is Synchronous Rotation?

Objective

To combine an analogous situation in the classroom with direct observations already made so that students will better understand the rotation and orbital revolution of planets.

Time Required: 1 hour

Saturn System Analogy: Moons that are locked in synchronous rotation with Saturn (e.g., Iapetus)

Keywords: Center of Figure, Center of Mass, Hemisphere, Revolution, Rotation, Synchronous

MATERIALS

- Desk chair that rotates
- Rubber, styrofoam, or tennis ball
- Pencil or long dowel
- Marking pen
- Desk lamp or overhead projector
- Optional: strong adhesive tape

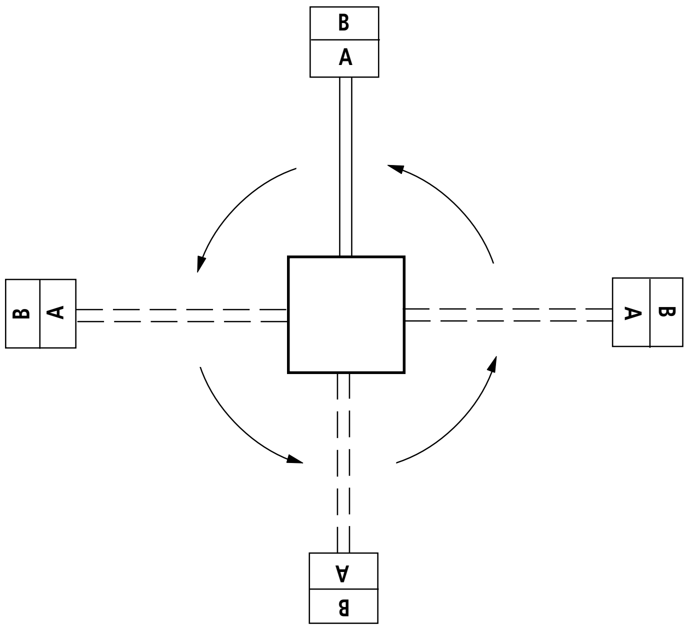
Discussion

Anyone who looks at the Moon notices that the same features always appear facing Earth. A natural conclusion might be that the Moon does not rotate. In fact, the Moon is rotating synchronously as it orbits around Earth (i.e., it is spinning at the same speed that it is going around Earth). Synchronous rotation is common throughout the solar system. It is found among the satellites of Mars, Jupiter, and Saturn. Pluto and its moon Charon are locked in mutual synchronous rotation, with both of them keeping the same faces towards each other.

Objects in Earth orbit are in free fall. A satellite assumes what is called a gravity gradient orientation, with the heavy end facing down indefinitely. (This is very convenient for some types of spacecraft, such as weather satellites.) Thus, the satellite is in synchronous rotation because it keeps the same end oriented towards Earth's center, completing one rotation as it completes one revolution around the world.

The fact that we see the Moon in synchronous rotation tells us something about the distribution of mass inside it. Specifically, "the center of mass" of the Moon is offset from the "center of figure" (its geometric center) by a few kilometers. This offset is enough to make the Moon assume a gravity gradient orientation and is indicated by its synchronous rotation.

To understand the difference between center of mass and center of figure, consider a barbell. A regular barbell has equal metal weights separated by a rod. Its center of mass is found in the middle of the rod, where it balances. Geometrically, the center of figure is at the same point.



A moon in synchronous rotation keeps the same hemisphere facing the planet, just as this diagram illustrates. At each position, side "A" on the small block faces the larger block. For that to be so, the smaller block is observed to rotate 90 degrees between each position. Though detached from Earth, the Moon behaves this way. Pluto and its moon Charon behave exactly as this diagram shows: Pluto and Charon keep the same faces towards each other.

Now consider a special barbell that has one set of weights replaced by wood shaped just like the metal weights. The geometric center of figure is still in the middle of the rod. But the center of mass is now much closer to the metal-weighted end — grab the special barbell in the middle of the rod to confirm the displacement of the center of mass.

Procedure

Stick the pencil or dowel (for use as a handle) through the ball along a diameter; this simulates the Moon. With the marking pen, write a large letter or number every 90 degrees around the circumference of the ball. The handle will either be held at arm's length by a student sitting in the chair or it can be taped to the armrest of the chair. Place the chair (Earth) a few feet away from the desk lamp or overhead projector (the Sun). The students can stay in their seats for this demonstration or they can gather in a circle around the Sun–Earth–Moon system.

Ask the students if the Moon rotates. Most will say no, since they have seen the same face of the Moon whenever they have looked up in the sky at it. Choose a student to sit in the chair and watch the ball-Moon with numbers/letters on its quadrants.

Slowly turn the student in the chair and ask that student if the view of the Moon is changing. The answer will be no; the hemisphere the student observes is always the same. In contrast, the other students will see the different quadrants appear as the chair makes one full rotation. This proves that the Moon rotates, even though it presents the same face to Earth (the student in the chair).

Historical and Scientific Notes

Synchronous rotation is common among the many moons orbiting planets in the solar system. Synchronous rotation beyond the Earth–Moon system may first have become apparent with Jean Dominique Cassini's discovery of Saturn's moon Iapetus in 1671. He found that he could see this satellite on only one side of its orbit around Saturn.

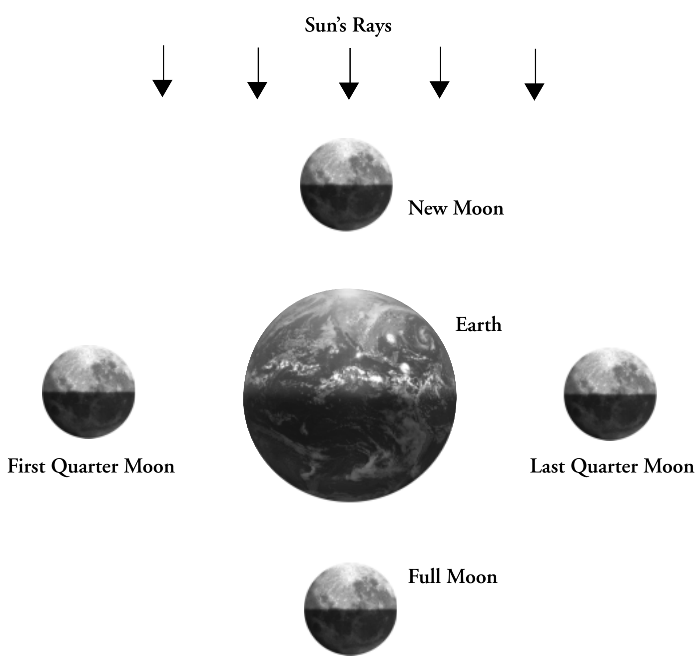
We now know that Iapetus is in synchronous rotation and that one hemisphere reflects light well (permitting Cassini to see the moon when that hemisphere faced Earth) while the other hemisphere is a very poor reflector (making Iapetus invisible in his telescope). The dark hemisphere of Iapetus faces the direction Iapetus moves in its orbit. The origin of Iapetus' two-faced behavior is an open question, hopefully to be answered by the Cassini spacecraft.

Additional Observations and Questions

Careful observers will also distinguish the day and night sides of the ball-Moon. The student in the chair will see the changing shape of the illuminated portion of the ball-Moon — its phases — as he/she carries it around one revolution. The students surrounding the "Sun–Earth–Moon" system will not see the phase change, though each one will see the ball-Moon with a different phase — crescent, half, gibbous, full — due to each student's individual viewing angle.

The illuminated hemisphere always faces the Sun and looks virtually the same for all lunar positions for an observer anywhere outside the Earth–Moon system. The fraction of the illuminated hemisphere visible to an observer inside the system changes over a full revolution of the Moon.

This demonstration assumes that the Moon orbits Earth in a perfect circle and that we can see only one-half of the Moon's spherical surface. In fact, the Moon's orbit is elliptical. The elliptical orbit changes the Moon's orbital speed over time, causing it to move faster and slower than the exact synchronous speed of a circular orbit. Because it is



View from above Earth's North Pole. (Figure is not to scale.) The illuminated hemisphere always faces the Sun and looks the same for all lunar positions for an observer anywhere outside the Earth–Moon system. The fraction of the illuminated hemisphere visible to an observer inside the system changes over a full revolution of the Moon.

sometimes ahead and sometimes behind where it would be in a circular orbit (and because of variations in the angle of its orbital plane relative to that of Earth), we can actually observe up to 59 percent of the surface. Over several months, careful binocular or telescopic observations of features near the edge of the lunar disk show this effect, which is called libration.

How are tides caused in Earth's oceans? The water responds to the gradient in the Moon's gravity (across the diameter of Earth) and bulges of water, causing high tides, appear on opposite sides of our planet.

The different types and relative infrequency of solar and lunar eclipses are related to the ellipticity and inclination of the Moon's orbit. Why?

Science Standards

A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity.

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position and motion of an object can be described by locating it relative to another object in the background.

LEVEL 2 (GRADES 3–5)

Knows that Earth's gravity pulls any object toward it without touching it.

Knows that when a force is applied to an object, the object either speeds up, slows down, or goes in a different direction.

Knows the relationship between the strength of a force and its effect on an object (e.g., the greater the force, the greater the change in motion; the more massive the object, the smaller the effect of a given force).

LEVEL 3 (GRADES 6–8)

Understands general concepts related to gravitational force (e.g., every object exerts gravitational force on every other object; this force depends on the mass of the objects and their distance from one another; gravitational force is hard to detect unless at least one of the objects, such as Earth, has a lot of mass).

Understands effects of balanced and unbalanced forces on an object's motion (e.g., if more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude; unbalanced forces such as friction will cause changes in the speed or direction of an object's motion).

Knows that an object that is not being subjected to a force will continue to move at a constant speed and in a straight line.

LEVEL 4 (GRADES 9–12)

Knows that the strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

Knows that laws of motion can be used to determine the effects of forces on the motion of objects (e.g., objects change their motion only when a net force is applied; whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object; the magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force).

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

Knows that learning can come from careful observations and simple experiments.

LEVEL 2 (GRADES 3–5)

Knows that scientific investigations involve asking and answering a question and comparing the answer to what scientists already know about the world.

Plans and conducts simple investigations (e.g., formulates a testable question, makes systematic observations, develops logical conclusions).

LEVEL 3 (GRADES 6–8)

Establishes relationships based on evidence and logical argument (e.g., provides causes for effects).

***Teachers** — Please take a moment to evaluate this product at* http://ehb2.gsfc.nasa.gov/edcats/educational_brief.
Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — Synchronous Rotation

Procedure

1. One student sits in the rotating chair holding the marked-up ball. What marking does the student see? What marking do the other students see?

2. The seated student rotates one-quarter turn (90 degrees).

3. Discuss which marking you see on the ball versus which marking the student in the chair sees.

4. The seated student rotates (in the same direction as before) another quarter turn.

5. Again, compare the marking the you see versus the marking the student in the chair sees.

6. Continue rotating by quarter turns until the seated student returns to the starting position.

Questions

Does the Moon rotate?

Does the student in the chair think that the “moon” rotates?

Can you determine the day and night sides of the moon with this experiment? How?